UNIVERSITÄT
BERN

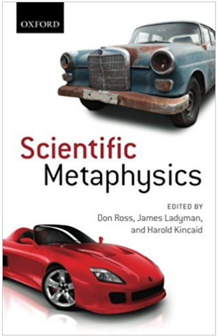
How Scientific Can a Metaphysics of Quantum Mechanics Be?

matthias.egg@philo.unibe.ch

New Topics in Quantum Foundations
Lausanne, 29 November 2018

Outline

Good and Bad Metaphysics



(2013)

Scientific Metaphysics

"...to explore what a metaphysics looks like that is judged by scientific standards and that avoids appeals to intuition" (Kincaid 2013, p. 1)

- What are "scientific standards"? A liberal interpretation threatens to let in too much metaphysics.
- But an over-restrictive interpretation creates a tension with the kind of scientific realism on which the project of scientific metaphysics is based: science is supposed to give us knowledge about mind-independent reality beyond the observable phenomena.

QM as a Problem for Scientific Metaphysics

- Different versions of quantum mechanics (Everett, Bohm, collapse theories) make radically different claims about reality, and scientific standards do not give clear preference to any one of them.
- The choice between them thus depends on the kind of intuitions (e.g., about explanatory power) that scientific metaphysics seeks to avoid.
- Two possible lines of response (cf. Ladyman 2012):
  1. The alleged problem of underdetermination will be solved scientifically in due course.
  2. There is no real problem, so opting for one of its "solutions" is an exercise in idle metaphysics.

Only a Temporary Problem?

- It may indeed become possible to experimentally test collapse versions of QM against no-collapse versions, but these tests will not resolve all the differences *within* those camps.
- Consequently, one might hope for progress on the theoretical front: "empirically equivalent theories may turn out to differ when they are extended to new domains" (Ladyman 2012, 44).
- However, the extension of QM to the relativistic theory of quantum fields (QFT) does not indicate any alleviation of the problem of underdetermination.
  - Applications of QFT (in particular, scattering theory) "solve" the measurement problem by fiat, simply assuming definite final states.
  - This makes QFT a highly successful predictive apparatus, but not a theory about which one could directly be a scientific realist.
  - There are research programs seeking to extend solutions of the measurement problem from QM to QFT, but the competition between them inherits (a modified version of) the old underdetermination problem.

The Measurement Problem as a Piece of Unscientific Metaphysics?

- Sociologically, it's hard to denounce the measurement problem as unscientific, for at least part of the work on it is performed by physicists and mathematicians, published in physics journals and funded by standard institutions of scientific research funding.
- True, the majority of physicists does not worry about the measurement problem, but if metaphysical questions were to be decided in this way, then instrumentalism about QM should be our first choice.
- Against this, Ladyman and Ross (2007, 2013; henceforth "L&R") have argued for a way to dissolve (rather than to solve) the measurement problem that is supposed to be compatible with scientific realism.

What Is (and Is Not) Claimed in the Following

- I do not dispute L&R's dismissal of a simplistic realism-versus-instrumentalism dichotomy. Admittedly, there is much within the formalism of QM about which one can be a realist without being committed to any realistic solution of the measurement problem.
- Nor do I criticize their position for being only a partial realism (Esfeld 2013). (I endorse a version of partial realism myself; see Egg 2014.)

Thesis to be defended

- L&R's dissolution of the measurement problem is not supported by the arguments they draw from naturalized metaphysics or ontic structural realism (OSR).
- Furthermore, it undermines some specific commitments that should be part of any kind of realism, even the minimal kind that they themselves defend.

Traditional Formulation of the Measurement Problem

Standard example

- Basis states of the measured quantum system: $|0\rangle_S$ and $|1\rangle_S$.
- Possible final states of the measurement apparatus: $|\text{“}0\text{”}\rangle_A$ and $|\text{“}1\text{”}\rangle_A$.
- Problem: the state $a|0\rangle_S|\text{“}0\text{”}\rangle_A + b|1\rangle_S|\text{“}1\text{”}\rangle_A$ does not seem to describe anything we observe, if a and b are both nonzero.

- Why should we assign quantum states to the measurement apparatus? The usual rationale is that it is supposed to be composed of a large number of quantum particles.
- L&R reject this supposition. Their ontic structural realism (OSR) entails a “hostility to the idea that macroscopic objects are fundamentally made of microscopic ones” (2007, 182).
- But do the arguments for OSR really undermine the formulation of the measurement problem?

L&R's Objections to the Measurement Problem

Objection 1: against philosophical accounts of composition

L&R criticize traditional accounts of composition for not paying sufficient attention to how composition is treated in the various sciences: "We have no reason to believe that an abstract composition relation is anything other than an entrenched philosophical fetish" (2007, 21)

Reply

- The formulation of the measurement problem does not depend on such an abstract composition relation.
- Instead, the rules of composition within QM itself tell us that the compound systems can be in superposed states just as the elementary systems can.

Objection 2: Doubts about fundamental objects

The historically most important arguments for OSR come from the the indistinguishability postulate in quantum statistics and the non-supervenience of entanglement relations. The ensuing questions about the identity and individuality of quantum particles suggest that there are no objects at the fundamental level.

Reply

Yes, particles are not fundamental and they may not be individuals, but this is irrelevant to formulating the measurement problem.

- The QM of composite systems is insensitive to whether the components are regarded as individuals or not; only cardinality matters.
- Various non-fundamental systems (atoms, molecules, fullerenes,. . .) have been shown to come in superposed states, and nothing more is required to formulate the measurement problem.

Objection 3: no particles in quantum field theory

Even the cardinality of particles becomes unstable in quantum field theory. Particles are no longer persistent objects, but mere excitations of quantum fields. It makes no sense to say that larger objects are "made of" such entities.

Reply

- In spite of this, particles exist in the sense of being real patterns, identifiable at an appropriate time and energy scale (rainforest realism; L&R 2007, Ch. 4)
- It is at this scale that the measurement problem is formulated. Quantum field theory is irrelevant to it.

(Aside: the converse does not hold – one needs to address the measurement problem to make sense of quantum field theory.)

Objection 4: lack of empirical justification

"The application of the quantum formalism to macroscopic objects is not necessarily justified, especially if those objects are importantly different from microscopic objects, as indeed they are, in not being carefully isolated from the environment. [From a naturalistic viewpoint], the representation of macroscopic objects using quantum states can only be justified on the basis of its explanatory and predictive power and it has neither." (L&R 2007, 182)

Reply

- Although there is indeed no *direct* empirical justification for assigning quantum states to macroscopic objects, there is overwhelming indirect (scientific, not just philosophical!) justification for it.
- Decoherence theory, an explanatorily and predictively powerful part of QM routinely assigns quantum states to macroscopic objects (the environment).

L&R's Positive (Bohrian) Proposal

"The predictive success of QM in this context [of measurement] consists in the successful application of the Born rule, and that is bought at the cost of a pragmatic splitting of the world into system and apparatus." (L&R 2007, 182)

- The application of the Born rule is indeed successful if we insist (with Bohr) that the apparatus needs to be described classically in the sense of not being in any superposed state.
- L&R (2013, 134) explicitly sympathize with Bohr's early version of the Copenhagen interpretation, which differs from later versions by refusing to give any story about collapse of the wave function.
- The question now is whether this is compatible with realism.

The Problem with “Measurement”

The Born rule (technically simplified formulation)

Let a quantum system be in state $|\psi\rangle = c_1|\varepsilon_1\rangle + c_2|\varepsilon_2\rangle + \ldots$, where the $|\varepsilon_1\rangle,\ |\varepsilon_2\rangle, \ldots$ correspond to the possible outcomes of a certain measurement. Then such a measurement yields the result corresponding to $|\varepsilon_i\rangle$ with probability $|c_i|^2$.

- The problem with the reference to probabilities of measurement results is that it is notoriously unclear what counts as a “measurement” (Bell 1990).
- Such an imprecise notion should not occur in a basic assumption of physics. This is why realistic versions of QM (e.g., Everett, Bohm, GRW) seek to derive the Born rule by giving a physical account of what it is to be a measurement.
- Bohr, on the other hand, denies the need for such an account, as L&R (2013, 134) point out approvingly.

"Measurement" without Analysis

- Admittedly, any theory has to operate with some basic notions which are not amenable to further analysis, so why not simply treat "measurement" as such a notion?
- This works well for situations in which we all agree whether the notion applies or not. But what about ambiguous cases, for example, a device that displays a measurement outcome which is not (even indirectly) observed by anyone? ("indirect observation" in the sense of "informational connectedness", L&R 2007, 307)
  - If one insists that the Born rule does also apply to such cases, one implicitly accepts spontaneous collapses (i.e., one of the solutions to the measurement problem that L&R sought to avoid).
  - If it doesn't apply, this means that the presence of an observer makes a difference to the physical process, whereas naturalistically, an observer should be viewed as just another measuring device.

Verificationism vs. Realism

- One could deny that there are any facts of the matter concerning unobserved measurements, because such events (by definition) do not make any difference to what we observe.
- This is hard to square with realism, understood as a stance that refuses to limit reality to what we can observe (or worse still, to what we actually *do* observe).
- L&R are quite honest about how their verificationism limits the domain of what counts as real, but they only discuss an example with which most realists will readily agree: “there are no grounds for regarding the other side of [the Big Bang] as part of reality” (2007, 309).
- By contrast, many realists will think that something has gone deeply wrong if there is no longer a fact of the matter as to how our measurement devices behave when no one watches them.

L&R's Realism about Unobserved Data

Since L&R do not endorse standard realism anyway, could they not simply accept antirealism about unobserved measurements and still hold on to their brand of realism?

Probably not. First hint:

- In their discussion of real patterns, they acknowledge that "there are (presumably) real patterns in lifeless parts of the universe that no actual observer will ever reach" (2007, 203).
- Since patterns are "relations among data" (228), such realism about patterns presupposes realism about data regardless of whether they are observed or not.

A Closer Look at L&R's Realism: Objective Modality

- L&R (2007, Subsection 2.3.2) defend a commitment to objective modality as a crucial element of realism against van Fraassen's constructive empiricism.
- According to L&R, constructive empiricism's refusal to regard beliefs about non-actual states of affairs as justified neglects the fact that we can to some extent vary what becomes actual and still experience that our theories accurately predict what we observe.

  > Theories are always modalized in the sense that they allow for a variety of different initial conditions or background assumptions rather than just the actual ones, and so describe counterfactual states of affairs. (2007, 110)

- Therefore, the empiricist relies on a somewhat arbitrary boundary when confining the content of our theories to a description of what actually occurs.

Arbitrariness of the Modalized Born Rule

- If the Born rule is modalized in the above sense, it does give us knowledge not only about what actually occurs, but also about what would occur under different conditions. In that sense, L&R's approach to the measurement problem does not fall prey to their charge of arbitrariness against constructive empiricism.
- However, the approach invokes a boundary that is just as arbitrary, namely between what is observed and what actually occurs without being observed. The Born rule is silent about the latter set of events.
- It seems that both kinds of arbitrariness ought to be equally unacceptable to L&R. But then, they should reject their own approach to the measurement problem in the same way as they reject constructive empiricism.

Conclusion

- Ladyman's defense of scientific metaphysics depends on distinghishing between
  1. scientifically serious cases of underdetermination (which can be expected to be solved in due course), and
  2. purely metaphysical cases of underdetermination (which aren't worth worrying about).
- The case of underdetermination between different versions of QM does not seem to fit into either of these categories.
- In the context of this important example, scientific metaphysics either has to revert to the use of intuitions or it collapses into instrumentalism.
- Other recent attempts to avoid the dilemma between instrumentalism and too much metaphysics (Healey's pragmatist quantum realism, Bub's information theoretic realism) seem to face the same problem.

References

- Bell, J. S. (1990): "Against 'measurement' ". In A. I. Miller (Ed.), *Sixty-two years of uncertainty: historical, philosophical, and physical inquiries into the foundations of quantum mechanics,* 17–32. New York: Plenum Press.
- Egg, M. (2014): *Scientific Realism in Particle Physics: A Causal Approach.* Boston: De Gruyter.
- Egg, M. (forthcoming): "Dissolving the Measurement Problem Is Not an Option for the Realist". http://philsci-archive.pitt.edu/15237.
- Esfeld, M. (2013): "Ontic structural realism and the interpretation of quantum mechanics". *European Journal for Philosophy of Science* **3**, 19–32.
- Kincaid, H. (2013): "Introduction: Pursuing a naturalist metaphysics". In: Ross, D., Ladyman, J. and Kincaid, H. (Eds.): *Scientific Metaphysics*, 1–26. Oxford University Press.
- Ladyman, J. (2012): "Science, metaphysics and method". *Philosophical Studies* **160**, 31–51.
- Ladyman, J. and Ross, D. (2007): *Every Thing Must Go: Metaphysics Naturalized.* Oxford University Press.
- Ladyman, J. and Ross, D. (2013): "The world in the data". In: D. Ross, J. Ladyman and H. Kincaid (Eds.), *Scientific Metaphysics*, 108–150. Oxford University Press.